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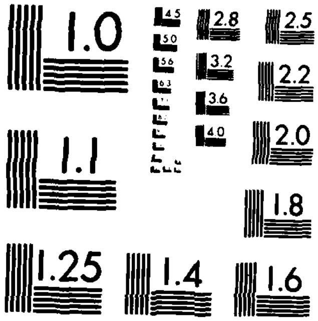
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TECHNICAL REPORT RR-84-8

ACOUSTO-OPTICALLY ADDRESSED FOURIER TRANSFORM MATCHED FILTERS

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AUGUST 1984

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35898-5000

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Matched filters made using the Vander Lugt technique are addressed using an acousto-optic beam deflector with good correlation signals resulting. This method may be used to address arrays of matched filters at high scan rates thus providing the large optical memory necessary for absolute object recognition and discrimination in a variety of applications.

ACKNOWLEDGEMENT

The authors would like to thank Dr. J. G. Duthie of the Army Missile Laboratory for suggesting this research and lending valuable advice when it was needed.

CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

One of the major problems in using Fourier transform matched filters for object recognition has always been the limited number of objects that could be recognized; or the memory of the system (Reference 1). To date, many novel techniques have been proposed including multiply explosing the photographic plate and using a holographic element to produce arrays of Fourier transformed images from which matched filters could be made (References 2 and 3). Both of these techniques, however, have limitations. The multiple exposure method is limited to about eight exposures while the holographic lens often contributes noise to the correlation signals. In this report, another technique is proposed and demonstrated to some degree of satisfaction. In this experiment, an acousto-optical beam deflector is used to address matched filters made using the visual Vander Lugt arrangement (Reference 4). This technique offers some promise of producing large arrays of matched filters which can be addressed in very nearly real-time due to the high frequency scanning abilities of modern acousto-optic beam deflectors. This technique would not be limited by the problems inherent in the other methods previously discussed.

II. THE ACOUSTO-OPTIC DEFLECTOR

In acousto-optical devices, a piezo-electric transducer is used to create longitudinal waves in a crystalline deflecting medium. These sound waves are produced at a frequency determined by an external frequency generator. As these longitudinal wavefronts propagate through the deflecting medium, the density of the crystal is altered which alters its index of refraction. Light waves are deflected when they encounter the crystal due to the modulation of the medium's refractive index (Reference 5).

The acousto-optical device used in these experiments was made by Isomet in September 1974. The device was model LD-401-2Y, with an aperture of 6.6mm and used tellurium dioxide as the deflecting medium. An Andret Corp. Frequency Synthesizer, model 6100, in conjunction with an EIN RF power amplifier, model 400 AP, provided the driving frequency.

For this A-O device, the operating frequency range was from 8 to 100 MHz. At all other frequencies no deflection could be detected with the naked eye. As the frequency decreased from 100 MHz, a number of orders appeared; however, the inteisities of the orders decreased simultaneously. As many as 18 negative orders were witnessed; however, the largest number of easily recorded orders was eight, at 14.2 MHz. For this experiment, the frequency was varied until the first order spots of highest intensity appeared. This occurred at a frequency of 70.2 MHz. These orders appeared at an angle of 4.06° from the undeflected zero-order. The tilt of the A-O device was then adjusted until the negative first order was maximized; the positive first order was at a minimum at this position.

Unfortunately the manufacturers of acousto-optic deflectors do not quote an MTF for their devices. This is not surprising in that they are not intended to be used in image manipulation. Figure 1 is an indication of the ability of the A-O device used in this investigation. The input was a Ronchi ruling haveing 50 lines per inch. The A-O device was quite effective in manipulating this low spatial frequency scene. However, when higher spatial

frequency scenes were used, some image degradation was observed. This was due, to some degree, to the collimation state of the laser beam carrying the image. A minimum of distortion would occur if the beam was well collimated as it entered the cell instead of being converging as in the present arrangement.

III. THE EXPERIMENT

A sketch of the basic experimental arrangement is given in Figure 2. It is essentially the standard Vander Lugt method for making matched filters, except for the addition of the acousto-optic deflector between the Fourier transform lens and the photographic plate. The input scene used was a transparency of an aerial photograph of Huntsville, Alabama containing both low and high spatial frequencies. The transparency was recorded on a high resolution Kodak 649F plate.

The coherent illumination was provided by a Hughes Helium-Neon laser (model 32218-c) with a 1 milliwatt output. The beam was expanded and collimated using a 25mm pinhole and 20x microscope objective followed by a 10cm focal length lens. First surface mirrors were used to increase the object beam path length to match that of the reference beam. Polarizers were used to insure the correct polarization of the two beams. The photographic plate was held in place by a standard three point mount. Micrometer x-y-z translators allowed careful positioning of the plate in the Fourier transform plane.

After exposing the 649F plate to the interference of the reference beam and the Fourier transformed zero-order object beam, the plate was developed using standard techniques (D-19 developer, Kodak stop bath and Hunt's fixer) (Reference 6). The plate was then replaced in the system and the correlation signal detected using an RCA model TC-1160 TV camera and displayed on a TV monitor or digitized using a Colorado Video model 321 image digitizer and the intensity displayed on a strip chart recorder or oscilloscope. The plate was then translated vertically so that the -1 order from the A-O device addressed the matched filter made with the zero-order. The correlation was then detected in the same plane as before but displaced in the vertical direction corresponding to the angle between the zero- and -1 order produced by the A-O deflector (Figure 3).

IV. EXPERIMENTAL RESULTS

The acousto-optic deflector used in this initial investigation was quite old and is by no means representative of devices currently available. The principle of operation is, however, the same today.

The efficiency of the device in deflecting the input light into the negative first order was measured using an NRC 880 Universal Shutter System as a power meter. A well collimated beam was incident upon the cell as the first measurements were made. The driving frequency was set at 70.2 MHz. The cell was tilted to maximize the -1 order and minimize the +1 order. The intensities of the incident, zero, positive, and negative first orders were present and measured. By dividing the intensity of the negative first order by the incident intensity, an efficiency of 20 percent was obtained. The positive first order was very weak and was therefore neglected.

The efficiency of the device was also determined for a tilt at which the positive and negative first orders appeared almost equal in intensity. The two intensities were added and divided by the incident intensity. Efficiency at this position was 10 percent. The angle of the device during this measurement was approximately 0°. From these results, it was determined that the A-O device deflects light twice as efficiently when tilted to maximize either the positive or the negative orders. This effect is explained by the fact that the A-O cell is most efficient when it is tilted at an angle adhering to the Bragg condition. The device was therefore returned to its original tilt, maximizing the negative first order.

By inserting and removing various lenses, the beam was transmitted through the A-O cell in various states of convergence and divergence. For all conditions, the efficiency was 20 percent. A strongly diverging or converging beam would most likely lose some efficiency, but for the usual f number (greater than 5) used in systems such as this, the effect is minute.

Initially, the experiment was arranged so that the deflected negative first order Fourier transformed image was interfered with the reference beam in an attempt to make a matched filter. The frequency shift induced by the A-O deflector proved to be enough to prevent the necessary interference at the film plate, so no filter could be made in this manner. Frequency shifting the reference beam with a second A-O device might have solved this problem, but it was not attempted. The alternative chosen was to make the matched filter with the undeflected zero-order which passes directly through the A-O deflector, then attempt to address this filter with the deflected negative first order. The input scene used was the transparency of Huntsville discussed earlier. The intensities of the object and reference beams were fixed approximately equal and Kodak 649F plates were used to record the filters. A typical filter is shown in Figure 4. After exposing and developing the plate, it was replaced in the original position. The correlation signal appeared as a very bright localized spot on the television monitor (Figure 2). The plate was then carefully translated vertically until the negative first order Fourier transformed image addressed the matched filter (see Figure 3). The correlation signal was detected after searching in the area shown in Figure 3. The correlation signal was displaced by the same angle as the deflected beam addressing the filter. The correlation signal itself was very well defined as shown in Figure 5, which is a photograph of the television monitor used to detect the correlation signal. An oscilloscope trace of a single TV line containing the correlation spot is given in Figure 6. There is very little noise in the signal as is characteristic of Vander Lugt matched filters addressed in the usual manner. The correlation signal also had the usual translational invariance expected from filters made and addressed using the Vander Lugt technique.

The final experiment involved measuring the correlation intensity as the driving frequency of the A-O device was changed. This provides information regarding how carefully regulated the frequency generator must be. The results are given in Figure 7. For a matched filter made with the zero-order then addressed with the first order, the driving frequency may vary by 100 KHz before the correlation intensity decreases by fifty percent. This of course depends upon the spatial frequency of the input scene as well as other factors.

V. CONCLUSIONS AND SUGGESTIONS

In this report a new method for accessing Fourier transform matched filters has been demonstrated. It seems likely that this method may circumvent the limited memory problem inherent with coherent recognition systems without adding a substantial amount of noise. It is not difficult to imagine a large matrix of matched filters addressed with highly efficient acousto-optic deflectors using a fast frequency sweeping x-y raster arrangement. The correlation signals detected from this array of filters would be spatially separated at the detector, which provides another advantage - discrimination. The correlation signal would correspond to one known particular filter in the array. Work has already begun in the construction of a large memory recognition system based on the preliminary results presented here.

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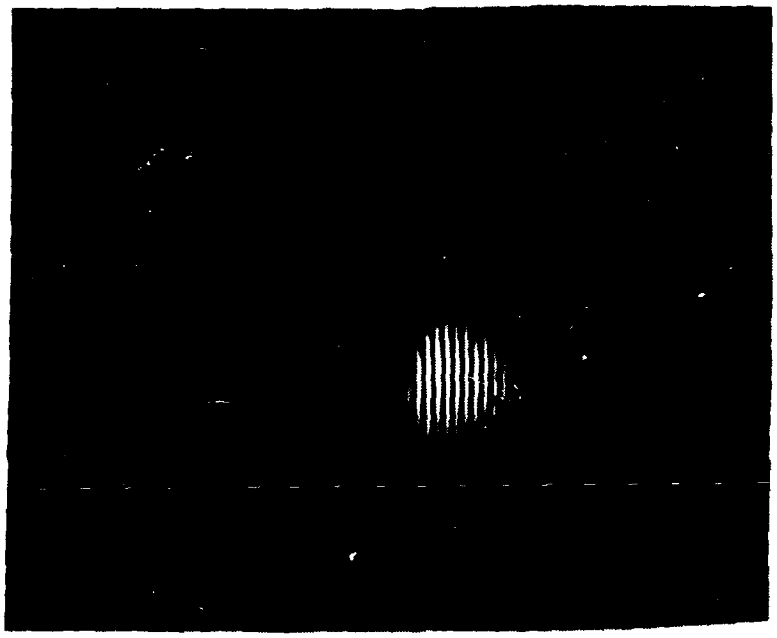
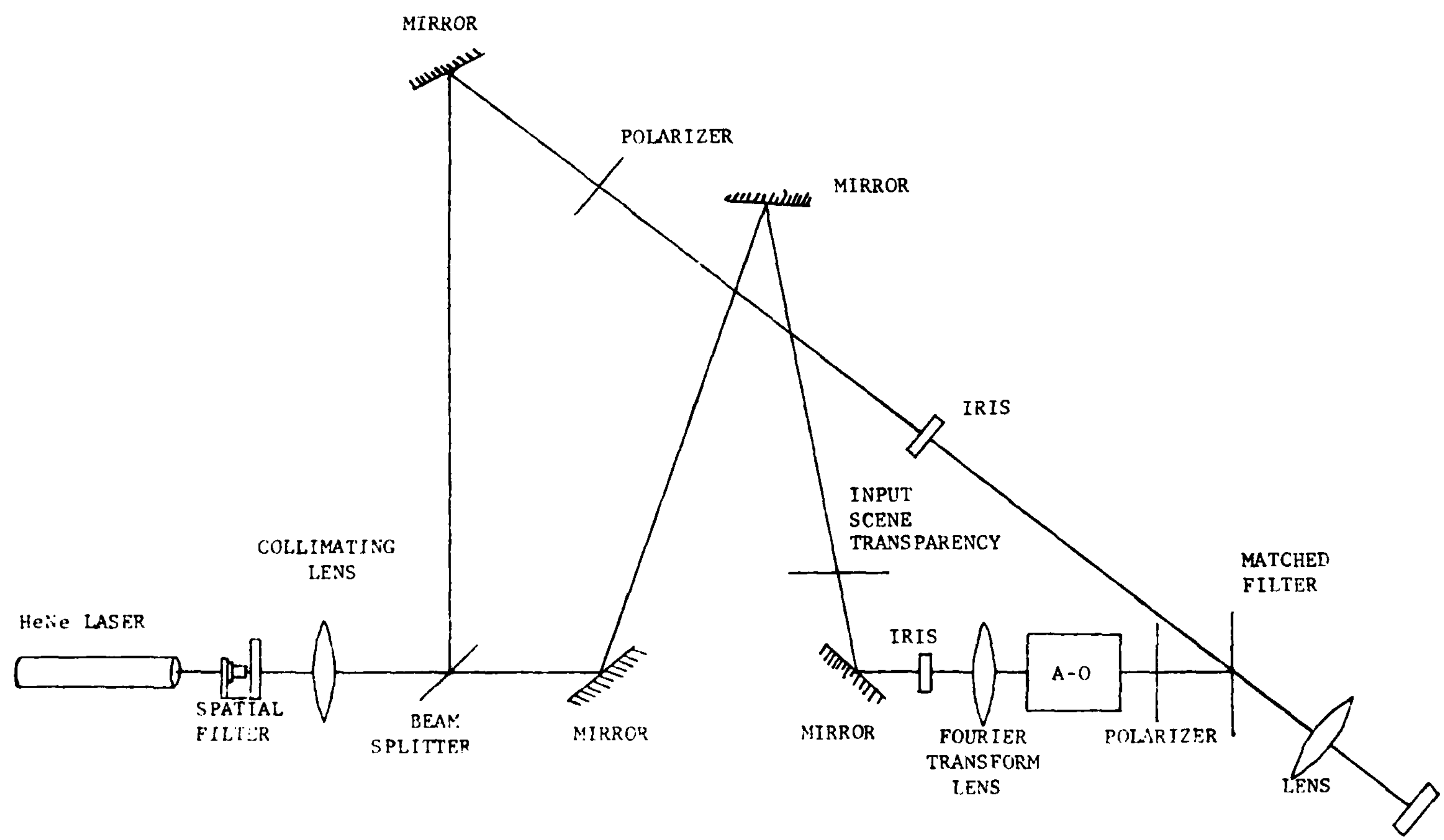


Figure 1. [illegible] order deflection [illegible] the input [illegible].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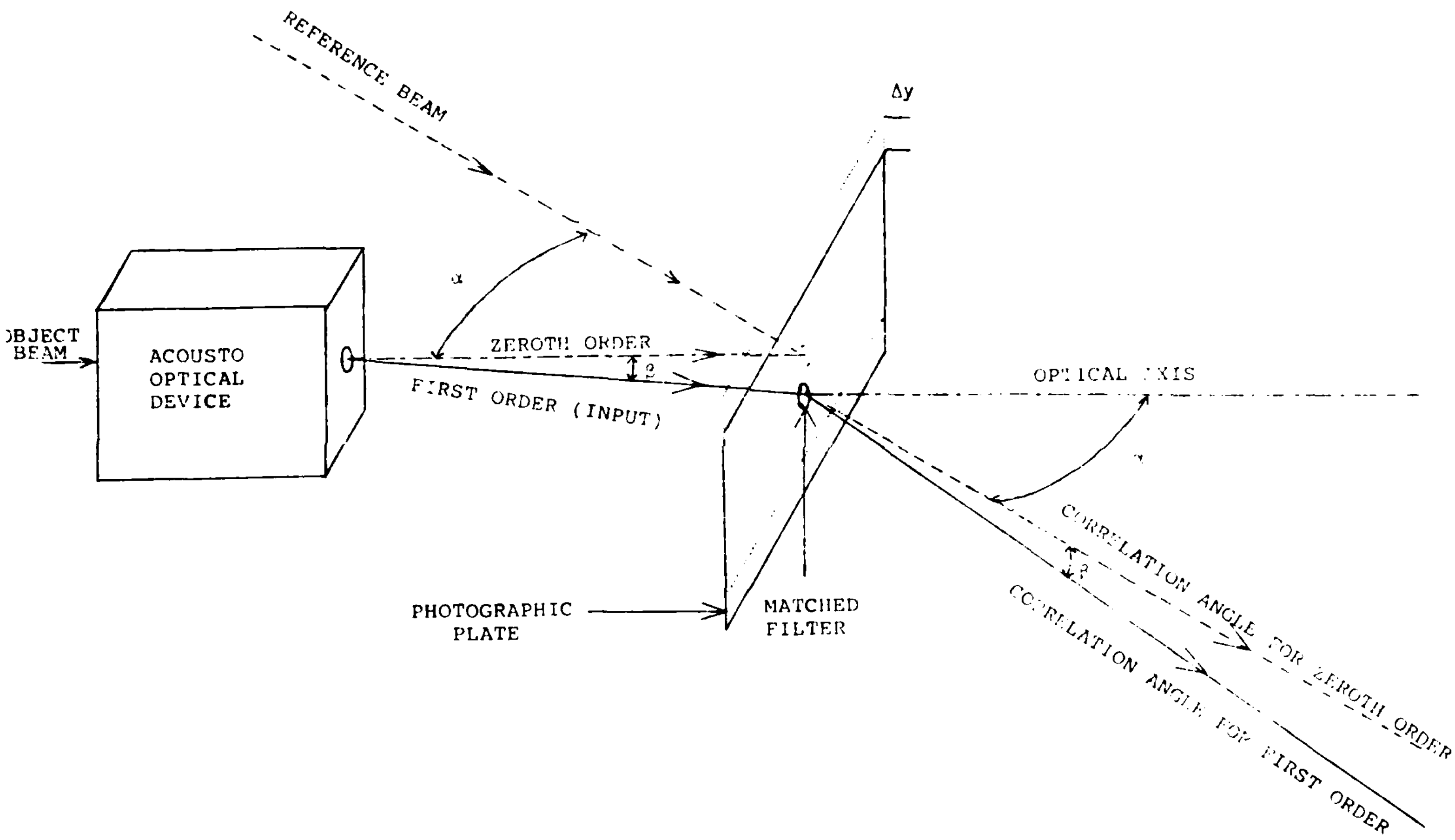

Figure 3. Detection of the correlation signal for a matched filter made with the zero-order deflection and addressed with the negative first order (The dotted line represents the position of the photographic plate when the matched filter was made.)

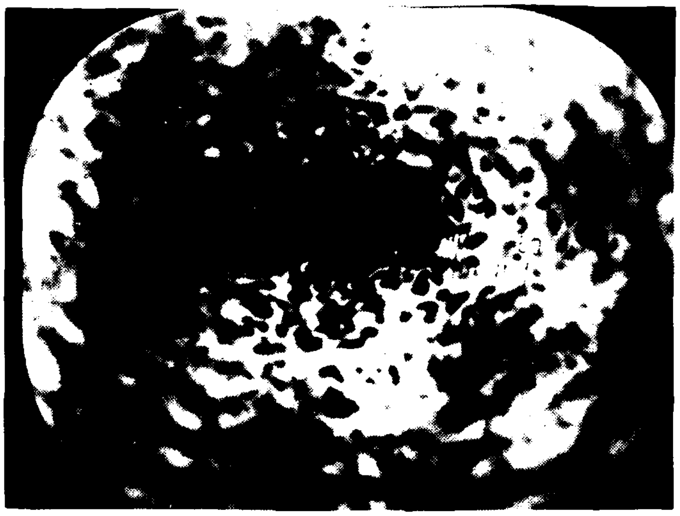

Figure 4. A photograph of a matched filter. The input scene was a transparency of an aerial photograph of Huntsville. The diameter of the darkest area is about 0.4 millimeters.

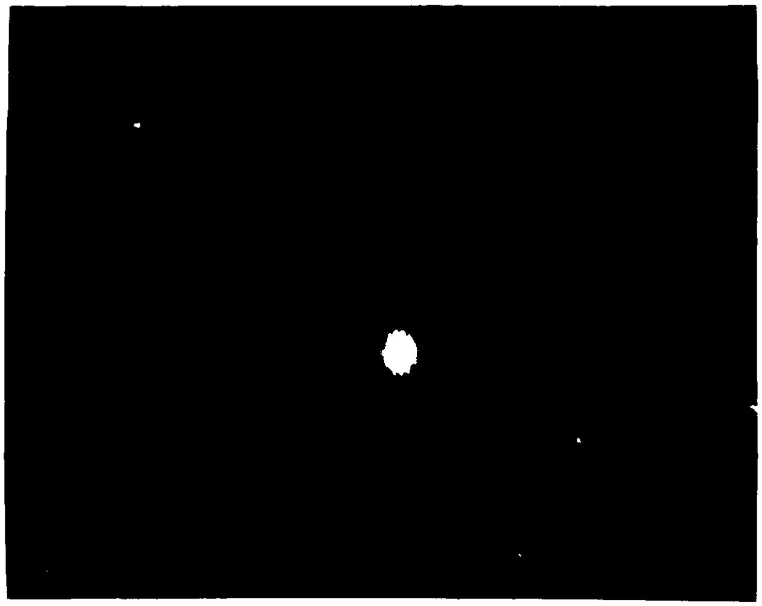

Figure 5. The correlation spot as it appeared on the TV monitor. The diameter of the spot was about 3 millimeters.

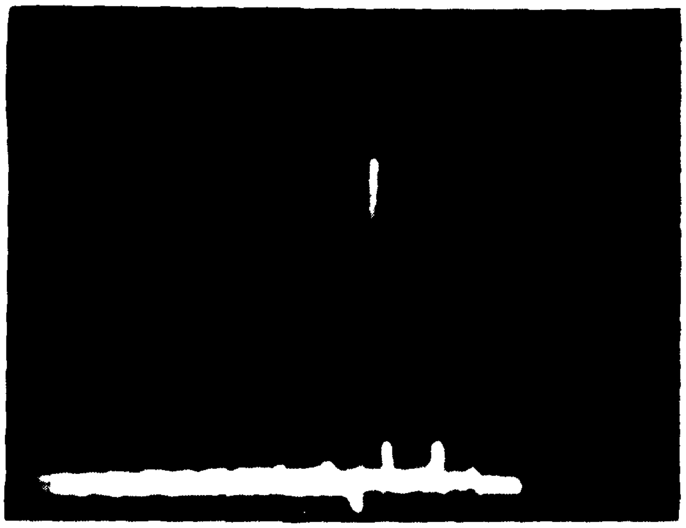

Figure 6. An oscill[illegible] containing the correlat[illegible].

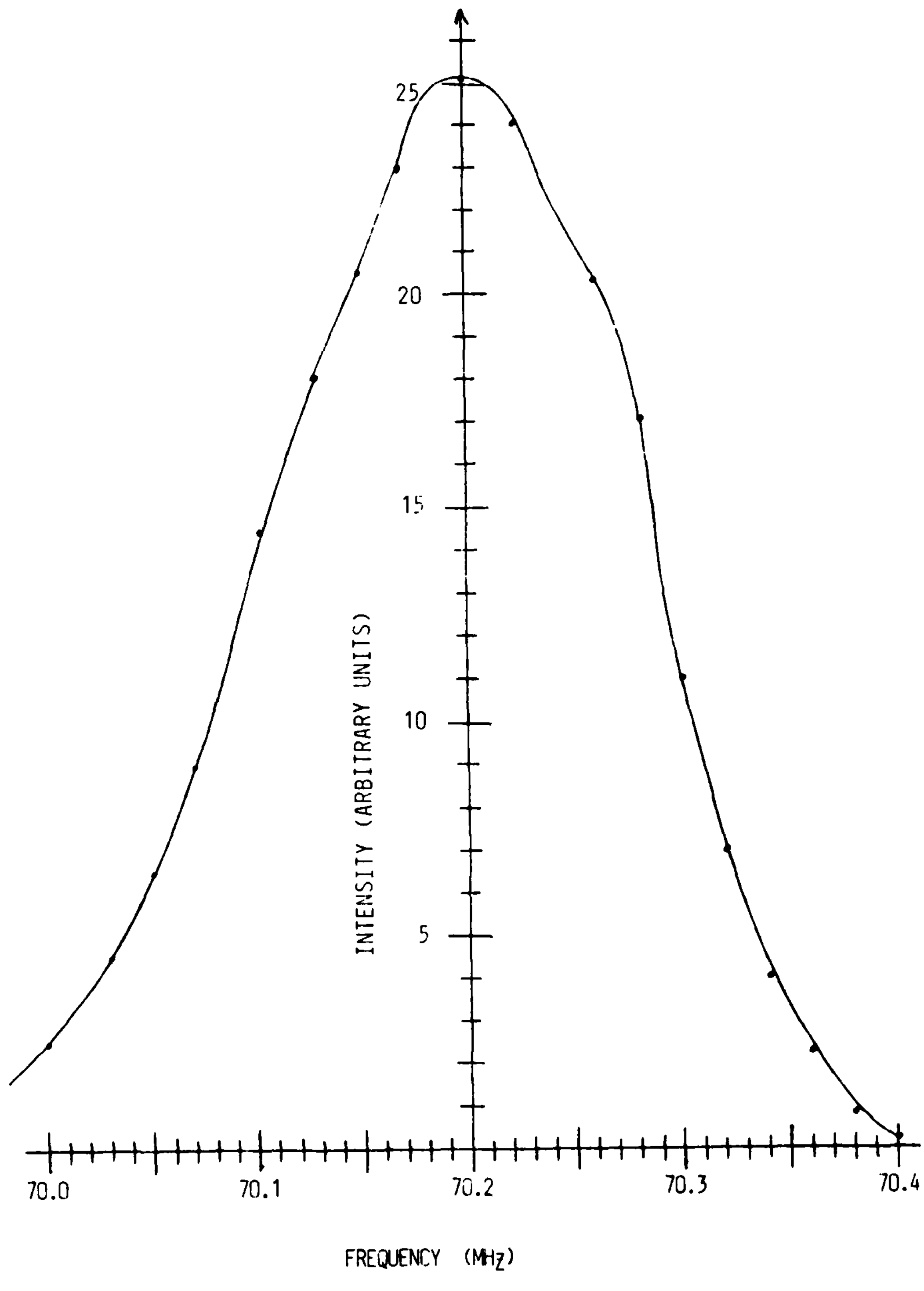

Figure 7. Correlation intensity vs driving frequency of the A-O device.

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